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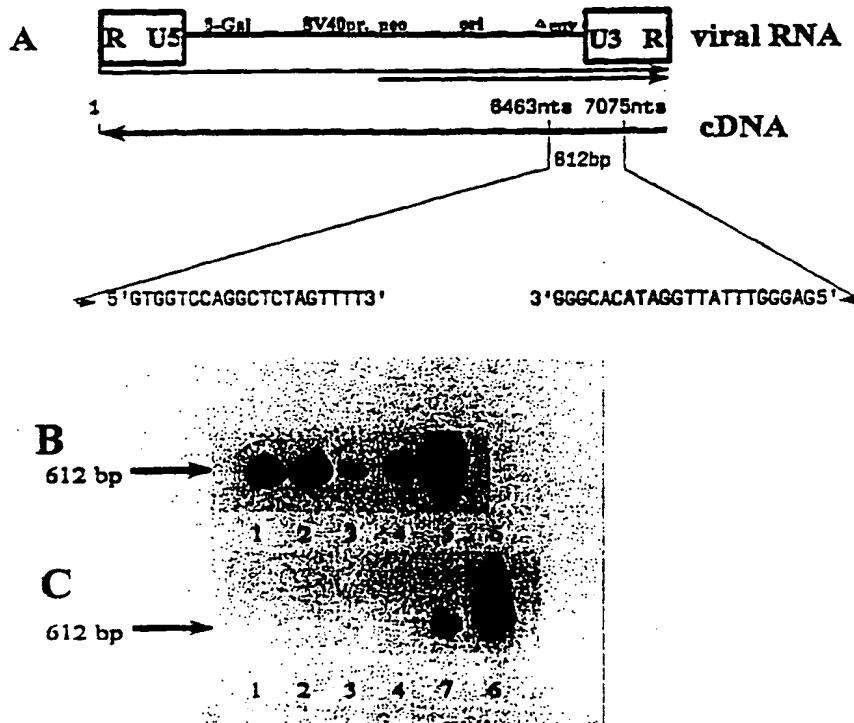
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(71) Applicants (for all designated States except US): BAVARIAN NORDIC RESEARCH INSTITUTE A/S [DK/DK]; 26B Smedeland, DK-2600 Glostrup (DK). GSF-FORSCHUNGSZENTRUM FÜR UMWELT UND GESUNDHEIT GMBH [DE/DE]; Ingolstädter Landstrasse 1, Neuherberg, D-85764 Oberschleissheim (DE).					
(72) Inventors; and					
(75) Inventors/Applicants (for US only): SALLER, Robert, Michael [DE/DE]; Juttastrasse 22, D-80636 München (DE). GÜNZBURG, Walter, H. [GB/DE]; Mitterfeldstrasse 11, D-85229 Ainhofen (DE). SALMONS, Brian [GB/DE]; Mitterfeldstrasse 11, D-85229 Ainhofen (DE).					
(74) Agent: BEHNISCH, Werner, Reinhard, Skuhra, Weise & Partner, Postfach 44 01 51, D-80750 München (DE).					

(54) Title: ENCAPSULATED CELLS PRODUCING VIRAL PARTICLES

**(57) Abstract**

The present invention relates to encapsulated cells producing viral particles, especially retroviral particles containing the genome of a viral vector carrying therapeutic genes, methods for the preparation of such encapsulated cells, as well as the use of such encapsulated cells for the treatment of diseases.



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## Encapsulated cells producing viral particles

The present invention relates to encapsulated cells producing viral particles, especially retroviral particles containing the genome of a retroviral vector carrying therapeutic genes, to methods for the preparation of such encapsulated cells, as well as to the use of such encapsulated cells for the delivery of genes, especially therapeutic genes, to target organs/cells.

### Background

The delivery of genes of therapeutic benefit to target cells is central to the concept of gene therapy. If gene therapy is to become a routine procedure it is of utmost importance that systems are developed that allow effective *in vivo* delivery of therapeutic genes to the target cells.

Viral vectors, and especially retroviral vectors are the most commonly used delivery vehicles for gene therapy (Morgan and Anderson, 1993). Most of the currently approved gene therapy protocols take an *ex vivo* approach in that cells are removed from the patient, genetically modified *in vitro* and then reintroduced into the patient. This procedure is cumbersome, expensive and limited to technologically advanced facilities. Further this kind of approach is limited to cells that can easily be isolated, cultured and reimplanted (Günzburg et al., 1995). Although an *in vivo* delivery of therapeutic genes would offer many advantages, in its present form this approach is both inefficient and problematic. A major problem, due to low efficiency of gene transfer, is the necessity for multiple applications of viral vector. The requirement for multiple rounds of vector delivery is not only tedious but also likely to be unsuccessful because of immune responses directed towards the virus particles.

One possible way in which these problems could be circumvented is through the direct implantation of cells producing viral particles. The implantation of cells producing viral particles containing the genome of a viral vector *in situ* next to the target organ or cells would also allow direct application of the viral vector to the target cells/organs.

Additionally, where the viral vector virus used is a retroviral vector virus, such an approach have an advantage over multiple single high dosage applications, since the

chances of the vector virus being present at the time when a target cell undergoes replication, and thus being able to infect the target cell is increased. Furthermore a lower but continuous release of viral particles may be advantageous in escaping host immune responses against the viral particle.

For an effective delivery of viral vectors, the cells producing viral particles should be able to survive long periods in the host after implantation, and viral particles must be produced during this period and released from the cells. In the absence of a significant immune response, for instance after implantation in the brain, these cells can survive over prolonged periods (Culver et al., 1992; Ram et al., 1993). However to achieve successful implantation at other sites in the body, the producer cells must be protected from the immune system.

The long term effectiveness of this approach thus depends on (1) protection of the cells from the host immune system, which will normally eliminate cells producing viral particles, especially if the cells producing the viral particles are from a different species as is usually the case for such cells and (2) survival of the cells *in situ* for extended periods, which may require vascularisation.

Encapsulation of cells in permeable structures that allow the release of certain biologically active molecules but protects the cells producing these molecules from the host immune system has met with some success (for a review see Chang, 1995). Cells that have been genetically modified to produce human growth hormone (hGH) (Tai and Sun, 1993) or a secreted form of human adenosine deaminase (Hughes et al., 1994) have been encapsulated. In both of these studies, cells were encapsulated in poly-L-lysine-alginate microcapsules and the cells were shown to survive for long periods in culture. This was accompanied by long term production of the enzyme or hormone. Further, it was shown (Tai and Sun, 1993) that upon transplantation of the microcapsules into mice, the cells remained viable for 1 year and they continued to produce hGH, demonstrating that the capsules protect the transfected cells from destruction by the host immune system.

Cell encapsulation has also been reported using other materials. Baby hamster kidney cells genetically modified to produce nerve growth factor have been encapsulated in polyacrylonitrile/vinyl chloride and implanted in rat brain. The encapsulated cells

survived for at least 6 months and continued to produce NGF (Winn et al., 1994; Deglon et al., 1995).

Additionally, hepatocytes have successfully been encapsulated in a polyelectrolyte complex of cellulose sulphate and polydimethyldiallyl ammonium (Stange et al., 1993). More than 90 % of the encapsulated hepatocytes retained their viability and in contrast to hepatocytes grown as monolayers, the encapsulated cells showed an increased metabolic activity. It is not suggested herein that cellulose sulphate/polydimethyldiallylammonium capsules could support the growth other types of cells, such as cells producing viral particles, or allow the exit of viral particles from such capsules.

The preparation of cellulose sulphate capsules used in the present invention has been thoroughly described in DE 40 21 050 A1. Also the synthesis of the cellulose sulphate has been described in this patent application. Methods for a comprehensive characterisation of cellulose sulphate capsules have been extensively dealt with in H. Dautzenberg et al., Biomat., Art. Cells & Immob. Biotech., 21(3), 399-405 (1993). Other cellulose sulphate capsules have been described in GB 2 135 954. The properties of the cellulose capsules, i.e. the size, the pore size, wall thickness and mechanical properties depend upon several factors such as for example physical circumstances whereunder the capsules have been prepared, viscosity of precipitation bath, its ion strength, temperature, rapidity of addition of cell/cellulose sulphate suspension, constitution of cellulose sulphate, as well as other parameters described by the Dautzenberg group.

It has surprisingly been found that the continuous production of viral particles from implanted cells can be achieved by encapsulation of the cells in a polyelectrolyte complex. Although the pores of such capsules are large enough to allow antibodies and complement, known to inactivate virus (Welsh et al., 1975, Cornetta et al., 1990), to enter the capsules, we have found no evidence of gross immune or inflammatory responses, or of necrosis in the vicinity of implanted capsules. Additionally, it has surprisingly been found that the capsules according to the present invention become well engrafted in the host, and become rapidly vascularized. The encapsulated cells according to the invention thus permits long term delivery of viral vectors carrying therapeutic genes *in vivo*.

### Summary of the present invention

The invention then, inter alia, comprises the following alone or in combination:

Encapsulated cells producing viral particles comprising a core containing cells; and a porous capsule wall surrounding said core, said porous capsule wall being permeable to said viral particles;

encapsulated cells as above wherein said porous capsule wall consists of a polyelectrolyte complex formed from counter-charged polyelectrolytes;

encapsulated cells as above wherein said porous capsule wall consists of a polyelectrolyte complex formed from sulphate group-containing polysaccharides or polysaccharide derivatives or sulphonate group-containing synthetic polymers and polymers with quaternary ammonium groups;

encapsulated cells as above wherein the sulphate group-containing polysaccharides or polysaccharide derivative is cellulose sulphate, cellulose acetate sulphate, carboxymethylcellulose sulphate, dextran sulphate or starch sulphate, and the sulphonate group-containing synthetic polymer is a polystyrene sulphonate;

encapsulated cells as above wherein the polymer with quaternary ammonium groups is polydimethyldiallylammonium or polyvinylbenzyl-trimethylammonium;

encapsulated cells as above wherein the porous capsule wall consists of a complex formed from cellulose sulphate and polydimethyldiallyl ammonium;

encapsulated cells as above having the form of microcapsules with a diameter between 0.01 and 5 mm, preferably between 0.1 and 1 mm;

encapsulated cells as any above wherein said capsule consist a spongy cellulose sulphate matrix forming the interior of the capsule wall, surrounded by a capsule surface containing pores: said spongy matrix being filled with cells.

encapsulated cells as above wherein the surface pore size of the porous capsule wall is between 80 and 150 nm, preferably between 100-120 nm;

encapsulated cells as above wherein the viral particle produced by the encapsulated cells is a retroviral particle containing the genome of a retroviral vector;

encapsulated cells as above wherein the encapsulated cells producing retroviral particles is a packaging cell line transfected with an expression vector, said expression vector carrying a retroviral vector construct capable of infecting and directing the expression in target cells of one or more coding sequences carried by said retroviral vector construct; said packaging cell line harbouring at least one expression vector carrying genes coding for the proteins required for the retroviral vector construct to be packaged;

encapsulated cells as above wherein at least one of said coding sequences code for heterologous peptides selected from marker genes, therapeutic genes, antiviral genes, antitumor genes, and cytokine genes;

encapsulated cells as above wherein said marker gene is selected from the group consisting of marker genes which codes for proteins such as  $\beta$ -galactosidase, neomycin, alcohol dehydrogenase, puromycin, hypoxanthine phosphoribosyl transferase (HPRT), hygromycin and secreted alkaline phosphatase, and said therapeutic gene is selected from genes which codes for proteins such as Herpes Simplex Virus thymidine kinase, cytosine deaminase, guanine phosphoribosyl transferase (gpt), cytochrome P 450 and cell cycle regulatory genes such as SDI, tumour suppresser genes which codes for proteins such as p53 or antiproliferation genes which codes for proteins such as melittin, cecropin or cytokines such as IL-2;

encapsulated cells as above wherein the packaging cell line is selected from psi-2, psi-crypt, psi-AM, GP+E-86, PA317, and GP+envAM-12;

encapsulated cells as above wherein the expression vector transfected into the packaging cell line is pBAG, pLXSN, p125LX, pLX2B1, or pc3/2B1 or derivatives thereof;

a process for the preparation of encapsulated cells as above comprising suspending the cells producing viral particles in an aqueous solution of a polyelectrolyte, whereafter the suspension in the form of preformed particles is introduced into a precipitation bath containing an aqueous solution of a counter-charged polyelectrolyte;

a process as above wherein the particle formation takes place by spraying;

a process as above wherein the cells are suspended in an aqueous solution of a sulphate group-containing polysaccharide or polysaccharide derivative, or a sulphonate group-containing synthetic polymer;

a process as above wherein the sulphate group-containing polysaccharide or polysaccharide derivative is selected from cellulose sulphate, cellulose acetate sulphate, carboxymethylcellulose sulphate, dextran sulphate or starch sulphate, and the sulphonate group-containing synthetic polymer is a polystyrene sulphonate;

a process as above wherein the precipitation bath contain an aqueous solution of a polymer with quaternary ammonium groups;

a process as above wherein the polymer with quaternary ammonium groups is polydimethyldiallylammonium or polyvinylbenzyl-trimethylammonium;

a process as above wherein the cells are suspended in an aqueous solution of sodium cellulose sulphate, and introduced into a precipitation bath containing an aqueous solution of polydimethyldiallylammonium chloride;

a method as above wherein the aqueous cellulosesulphate solution is composed of 0.5-50 %, preferably 2-5% sodium cellulose sulphate and 2-10%, preferably 5% fetal calf serum in buffered saline.;

a method as above wherein the aqueous solution in the precipitation bath is composed of 0.5-50 %, preferably 2-10 %, or more prefered 3 % polydimethyldiallylammonium chloride in buffered saline;

encapsulated cells as any above produced by a process as above;

the use of the encapsulated cells as any above for the delivery of genes to target organ/cells comprising:

- a) Culturing the encapsulated cells in a suitable medium, and
- b) Implantation of the encapsulated cells into a living animal body, including a human;

the use as above wherein the target organ/cells is the mammary gland, or the pancreas; and

the use as above wherein the target organ/cells are the smooth muscle cells and other cell types surrounding the arteries.

#### **Objects of the present invention**

It is an object of the present invention to provide encapsulated cells producing viral particles, which allow the release of the viral particles produced by the cells from the capsule, and at the same time do not elicit a significant host immune or inflammatory response after implantation in a host.

It is a further object of the present invention to provide a process for the production of such encapsulated cells producing viral particles.

Still an object of the present invention is to provide a method for the delivery of genes, especially therapeutic genes, to target organs/cells by implantation of such encapsulated cells producing viral particles in a host, and thereby provide for the continuous production and release of viral particles in the target organs or near target cells.

#### **The Invention**

According to the present invention, encapsulated cells producing viral particles, which allow the release of the viral particles produced by the cells from the capsules, and at

the same time do not elicit a significant host immune or inflammatory response after implantation in a host, are provided.

The encapsulated cells according to the invention can be prepared by suspending the cells producing viral particles in an aqueous solution of a polyelectrolyte (e.g. selected from sulphate group-containing polysaccharides or polysaccharide derivatives or of sulphonate group containing synthetic polymers), whereafter the suspension in the form of preformed particles is introduced into a precipitation bath containing an aqueous solution of a counter-charged polyelectrolyte (such as for example a polymer with quaternary ammonium groups).

Sulphate group-containing polysaccharides or polysaccharide derivatives includes cellulose sulphate, cellulose acetate sulphate, carboxymethylcellulose sulphate, dextran sulphate or starch sulphate in the form of a salt, especially a sodium salt. The sulphonate group-containing synthetic polymer can be a polystyrene sulphonate salt, preferably a sodium salt.

Polymers with quaternary ammonium groups includes polydimethyldiallylammonium or polyvinylbenzyl-trimethylammonium, in the form of a salt thereof, preferably a chloride salt.

In a preferred embodiment of the invention the cells producing viral particles are encapsulated in a complex consisting of a complex formed from cellulose sulphate and polydimethyldiallyl-ammonium.

Such capsules are preferably prepared by suspending the cells producing viral particles in a solution containing 0.5-50%, preferably 2-5%, sodium cellulose sulphate and 5% fetal calf serum optionally in buffer. This suspension is then dropped by a dispensing system (e.g. air-jet system or piezoelectric system) while stirring into a precipitation bath containing 0.5%-50%, preferably 2-10%, or most preferred around 3% polydimethyl-diallylammonium chloride optionally in buffer. Capsule formation occurs within milliseconds and the capsules containing cells are kept in the precipitation bath for 30 seconds to 5 minutes and then washed. The rapidity of this method ensures that the cells are not unduly stressed during the whole procedure (Stange et al., 1993).

The capsules according to the invention have a variable diameter between 0.01 and 5 mm, but are preferably between 0.1 and 1 mm. Consequently, capsules can be made to contain a variable number of cells. Using the encapsulation process according to the invention, up to  $10^{10}$ , but preferably  $10^5$ - $10^7$  cells producing viral particles can be encapsulated in the polyelectrolyte complex.

Capsules composed of cellulose sulphate and polydimethyldiallyl ammonium have excellent mechanical properties and can be manufactured to consistent size and pore size.

The pore size of the capsules is between 80 and 150 nm, preferably between 100 and 120 nm.

The encapsulated cells can be cultivated in a normal cell culture medium (the nature of which depends on the encapsulated cells) at standard conditions of humidity, temperature and CO<sub>2</sub> concentration. During this culture period production of viral particles from the capsules into the cell culture medium can be demonstrated using either RT-PCR technology or by transfer of cell free (0.45 µm filtered) supernatant to target cells followed by the demonstration of viral infection by assay for the activity of marker proteins encoded by genes carried by the viral vector construct contained within the viral particle. If the marker gene carried by the viral vector is a gene conferring resistance to a specific compound upon the target cell, the titre of virus produced by the system can be ascertained.

After a suitable period in culture (normally not less than 1 hour and not exceeding 30 days), the cell containing capsules can be surgically implanted either directly, or by injection using a syringe into various areas of the body.

The viral particles produced by the encapsulated cells according to the invention can be based on any virus useful for gene therapy, including but not limited to adenoviruses, adenovirus associated viruses, herpes viruses or retroviruses; for a review see Günzburg and Salmons, 1995.

In a preferred embodiment of the invention, the encapsulated cells is a packaging cell line producing retroviral particles containing the genome of a retroviral vector construct carrying marker and/or therapeutic genes.

Retroviral vector systems consist of two components:

1) an expression vector (vector plasmid) carrying a retroviral vector construct which is a modified retrovirus in which the genes encoding for the viral proteins have been replaced by therapeutic genes optionally including marker genes to be transferred to the target cell. Since the replacement of the genes encoding for the viral proteins effectively cripples the virus it must be rescued by the second component in the system which provides the missing viral proteins to the modified retrovirus.

The second component is:

2) a cell line that produces large quantities of the viral proteins, however lacks the ability to produce replication competent virus. This cell line is known as the packaging cell line and consists of a cell line transfected with plasmids carrying the genes enabling the modified retroviral genome to be packaged. These plasmids directs the synthesis of the necessary viral proteins required for virion production.

To generate the packaged retroviral vector, the vector plasmid is transfected into the packaging cell line. Under these conditions the modified retroviral genome including the inserted therapeutic and optional marker genes is transcribed from the vector plasmid and the resulting modified retroviral genome is packaged into the retroviral particles. A cell infected with such a viral particle cannot produce viral particles since no viral proteins are present in these cells. However the retroviral vector construct carrying the therapeutic and marker genes is present and these can now be expressed in the infected cell.

WO 94/29437, WO 89/11539 and WO 96/07748 describe different types of retroviral vector systems useful for the purpose of the present invention.

The viral particles produced by the encapsulated cells according to the invention, can be constructed to contain the genome of a viral vector carrying genes encoding marker and/or therapeutic genes.

The marker or therapeutic genes carried by the viral vector can be, for example, genes which code for proteins such as  $\beta$ -galactosidase, neomycin, alcohol dehydrogenase, puromycin, hypoxanthine phosphoribosyl transferase (HPRT), hygromycin and secreted alkaline phosphatase or therapeutic genes which code for proteins such as Herpes Simplex Virus thymidine kinase, cytosine deaminase, guanine phosphoribosyl transferase (get), cytochrome P 450, cell cycle regulatory genes such as SDI, tumour suppresser genes which code for proteins such as p53, antiproliferation genes which code for proteins such as melittin, cecropin or cytokines such as IL-2.

In a special embodiment, the invention relates to the use of the encapsulated cells according to the invention in the treatment of tumours.

Many malignant tumours do not respond well to chemotherapy. The anti-cancer drugs used to treat tumours are in most cases applied systemically and therefore spread through the whole body of the patient. The high systemic dose of such drugs required for cancer treatment often is combined with unpleasant side-effects for the patient. One strategy by which these problems of high systemic concentration of anti-cancer drugs could be circumvented is by the direct application or by the activation of the drug directly in or near the tumour. This could be achieved by implantation of encapsulated cells according to the invention producing viral particles containing the genome of an engineered virus, especially a retroviral vector, carrying a gene encoding an anti-cancer drug, for example an activating enzyme capable of converting a prodrug to a cytotoxic agent, either into tumour cells or into nearby cells.

In one embodiment of the invention encapsulated cells producing retroviral particles containing the genome of a retroviral vector carrying tumour relevant enzymes such as cytochrome P450 or suicide genes such as but not limited to thymidine kinase which convert non-toxic drugs to one or more toxic metabolites are provided. Such encapsulated cells of the invention can be used for the treatment of cancers by implantation of the capsules in or near the tumours, e.g. tumours in the pancreas or the mammary gland.

Additional targeting can be obtained by the use of target cell specific regulatory elements and promoters for the direction of the expression of linked therapeutic genes to specific cell types.

Such target cell specific regulatory elements and promoters include, for example, pancreas specific regulatory elements and promoters including carbonic anhydrase II and  $\beta$ -glucokinase regulatory elements and promoters; lymphocyte specific regulatory elements and promoters including immunoglobulin and MMTV lymphocytic specific regulatory elements and promoters; mammary specific regulatory elements and promoters including Whey Acidic Protein (WAP), Mouse Mammary Tumour Virus (MMTV),  $\beta$ -lactoglobulin and casein specific regulatory elements and promoters and MMTV specific regulatory elements and promoters conferring responsiveness to glucocorticoid hormones or directing expression to the mammary gland. Other promoters include for example the CD4, CD34, and IL2 promoters. Said regulatory elements and promoters regulate preferably the expression of said retroviral vector.

Inducible promoters such as radiation inducible promoters, for example, the intercellular adhesion molecule-1 (ICAM-1) promoter, the epidermal growth factor receptor (EGFR) promoter and the tumour necrosis factor (TNF) promoter can also be used.

The following examples will illustrate the invention further, however they are not to be construed as limiting:

**Example 1**

Lipofection of PA317 with pBAG and isolation of G418 resistant cells:

Amphotropic NIH3T3 based PA317 packaging cells (Miller and Buttimore, 1986) were cultured in Dulbecco's modified Eagle's medium (DMEM) containing 10 % fetal calf serum. The cells were seeded in a 10 cm tissue culture dish at a density of  $3 \times 10^5$  cells one day prior to lipofection and then lipofected with 2  $\mu$ g of pBAG vector (Price et al., 1987) carrying a MLV (Mouse Leukemia Virus) based retroviral vector using the lipofectamine kit from GIBCO/BRL according to the manufacturers instructions. The cells were then diluted one to ten and cultured in the usual medium containing additionally 400  $\mu$ g/ml G418 (GIBCO/BRL). After 14 days colonies of G418 resistant cells were pooled.

**Example 2**

Microencapsulation:

$10^7$  cells were suspended in 1 ml of a buffered saline solution containing 2-5% sodium cellulose sulphate and 5% fetal calf serum and the suspension dropped using a dispensing system (air-jet system) into a precipitation bath containing 2-3% polydimethyl-diallylammonium in buffered saline. Capsule formation occurred within milliseconds followed by further constitution of an inner, more porous, layer for mechanical support essentially consisting of cellulose sulphate. The capsules containing cells are kept in the precipitation bath for 30 seconds to 5 minutes and then washed in DMEM (Stange et al., 1993). Batches obtained to different parameters as described above, i.e. concentration of sodium cellulose sulphate, flow of air-jet system and time in precipitation bath were used for biological studies. Representative examples of conditions are for example: 2.5% sodium cellulose sulphate, 2% polydimethyl-diallylammonium, and 1 minute in precipitation bath, or 1.5% sodium cellulose sulphate, 2% polydimethyl-diallylammonium, and 0.5 minute in precipitation bath, or 3% sodium cellulose sulphate, 3% polydimethyl-diallylammonium, and 2 minute in precipitation bath. The exact parameters are selected also taking into account the exact size of the capsules wanted, the thickness of the capsule wall as well as other properties.

### Example 3

Implantation of microcapsules into the mammary gland of mice:

The microcapsules were inserted into the mammary glands of female 2 month old BALB/c mice by "key hole" surgery and the entry site closed by 1 suture. Up to six capsules of 0.5 - 2mm diameter were inserted at each operation site.

In vitro studies of virus release from the microcapsules, the structure of the microcapsules and the effect of the capsule implantation into immunocompetent mice were studied using the following test methods:

**A)  $\beta$ -galactosidase activity**

Detection of infected cells by histochemical staining was performed as outlined previously (Cepko, 1989). The cells, capsules or tissue sections were washed with chilled PBS and then fixed with a 2% paraformaldehyde solution for 20 mins - 24hrs according to the thickness of the sample. After extensive washing with PBS, the cells, capsules or tissue sections were incubated in a solution containing the substrate X-gal (20mM K<sub>3</sub>FeCN<sub>6</sub>, 20mM K<sub>4</sub>FeCN<sub>6</sub>.3H<sub>2</sub>O, 2mM MgCl<sub>2</sub> and 1mg/ml X-gal) for at least 2 hours at 37°C.

**B) Infection**

4 x 10<sup>4</sup> target cells were seeded in 6-well tissue culture plates 6 hours prior to infection. Capsules containing virus producing cells were placed on top of the cells and polybrene (8 $\mu$ g/ml) was added to the medium. Four hours later the medium was exchanged to remove the residual polybrene. Five days later some wells were stained for  $\beta$ -galactosidase activity as described above, the others were trypsinised into larger tissue culture dishes and cultured in media containing 400 $\mu$ g/ml G418. 16 days later G418 resistant colonies were detected.

**C) RT-PCR analysis**

Virus particles from 5 ml of capsule culture medium supernatant were pelleted by ultracentrifugation (240,000xg, 1 hour, 4°C). The pellet was resuspended in lysis buffer (1% Triton 100, 0.5% sodium desoxycholate, 0.1% sodium dodecyl sulphate, PBS) and the RNA extracted by phenol extraction followed by ethanol precipitation, as previously described (Salmons *et al.*, 1986). The RNA was then reverse transcribed into DNA using the Ready-To-Go T-primed first-strand kit (Pharmacia). PCR amplification was performed using primers located within the env and the R of the MLV derived BAG vector LTR (Fig. 2A). The PCR amplification was performed in 100µl reaction mixtures consisting of 500mM KCl, 10mM Tris-HCl (pH8.3) 1.5mM MgCl<sub>2</sub>, 0.01% (w/v) gelatine and 100µM of each dNTP, 40pM of each primer and 2.5 units Taq polymerase (Perkin Elmer). The reactions were performed in a Perkin Elmer Cetus Therma cycler 9600 under the following conditions: 1 min. at 94°C, 2 min. at 53°C and 3 min. at 72°C for 35 cycles. The PCR products were separated on a 0.8% agarose gel and then they were transferred to Zeta probe membranes (BIORAD) and hybridised, as previously described (Indraccolo *et al.*, 1995), to a <sup>32</sup>P-labeled 612bp PCR fragment of the MLV genome generated using the same primers and pBAG as a template. MLV specific sequences were visualised using a Fuji phosphoimaging system (BAS 1000).

**D) PCR analysis**

Genomic DNA (1µg) was amplified by PCR using one primer located within the residual env sequences of the BAG vector and a second primer in the polyoma region of the plasmid outside of the retroviral vector sequences (Fig. 3B). PCR reactions were performed as described above using the following reaction conditions: 1 min. at 94°C, 2 min. at 50°C and 3 min. at 68°C for 35 cycles. The PCR product was hybridised with a <sup>32</sup>P-labeled 1.5kb XbaI DNA fragment from pBAG that is specific for the polyoma sequences.

## F) Electron microscopy

The specimens for scanning electron microscopy (SEM) and transmission electron microscopy (TEM) examination were rinsed in PBS (pH 7.35) and prefixed in 1% glutaraldehyde in PBS for 15 mins before postfixing in 2% OsO<sub>4</sub> for 15 mins. The samples were dehydrated in a graded series of ethanol and then divided into two groups. a) The SEM samples were critical-point-dried using CO<sub>2</sub> and coated with 1-3nm platinum (Emscope SC 500; Ashford, England). The coated specimens were examined in a 10kV field emission scanning electron microscope (Jeol JSM-6300F; Tokyo, Japan), with accelerating voltages of 5-10kV in secondary mode. b) The TEM samples were embedded in Epón. Ultrathin sections were double stained with uranyl acetate and lead citrate, and viewed in a Zeiss EM-10C (Oberkochen, Germany) transmission electron microscope.

## Results

### In vitro studies of virus release from the microcapsules:

Staining of the cells in the microcapsules obtained in Example 2 with the substrate X-gal as described in the above test for  $\beta$ -galactosidase activity revealed that they expressed the  $\beta$ -galactosidase gene encoded by pBAG (Fig. 1), as do nonencapsulated vector producing cells (not shown).

To demonstrate that virus particles are released from the cells in the microcapsules into the cell culture medium, RNA was prepared from pelleted virions harvested from capsule supernatants after various time periods in culture. This RNA was analysed by RT-PCR using primers complementary to the viral *env* and R regions as described under *RT-PCR analysis* above. An MLV specific, PCR generated, fragment of the expected size (612bp) was observed in the microcapsule culture medium for at least 6 weeks (Fig. 2B, lanes 1- 4), at which point analyses were discontinued. This fragment is not due to contaminating DNA since pre-treatment of the viral RNA with RNase prior to RT-PCR resulted in no signal (Fig. 2C; 1-4).

Production and release of infectious virus from the capsules could be verified by their co-cultivation as described under the test *infection* above with target cells, e.g. NIH3T3 (Jainchill *et al.*, 1969) or CFRK (Crandell *et al.*, 1973) cells. After 4 days co-cultivation, an aliquot of the target cells as well as the encapsulated packaging cells were stained for

$\beta$ -galactosidase activity as described above. The remaining target cells were selected for G418 resistance. Many of the co-cultured NIH3T3 and CFRK cells could be shown to express the  $\beta$ -gal gene (Fig. 3A).

To confirm that the target cells had acquired the  $\beta$ -gal gene by infection, target cells were tested by PCR. The BAG producing packaging cell line is based upon the PA317 cell line (Miller and Buttimore, 1986) and carries the thymidine kinase gene of Herpes Simplex Virus (HSV-TK), the product of which converts the prodrug ganciclovir into a cytotoxic drug. The target NIH3T3 or CFRK cells do not normally carry this gene. In an experiment where it could be demonstrated that the  $\beta$ -gal expressing co-cultured NIH3T3 and CFRK target cells were resistant to GCV indicating that no escape of BAG producing cells had taken place, genomic DNA was extracted from the target cells and analysed for presence of plasmid sequences outside of the vector by PCR (PCR analysis above). These sequences are present in the packaging cells since the BAG vector was lipofected into these cells in the form of the plasmid pBAG. However the virus produced from the packaging cells does not carry these plasmid sequences and so they should not be present in the target infected cells. Fig. 3B shows that no such plasmid sequences were detectable, compatible with infection of these cells with the BAG vector.

#### Structure of the microcapsules:

Sections of the microcapsules were prepared and their structure analysed by electron microscopy. The interior of the capsule consists of a spongy like matrix which is filled with cells (Fig. 4). Scanning electron microscopy of the surface of the microcapsules reveals the presence of pores that are large enough to allow the passage of retroviral vector particles out of the capsules since the white bar represents the average diameter of a retrovirus particle (Fig. 4).

**In vivo stability in immunocompetent mice:**

To determine the *in vivo* stability of the microcapsules and whether the microcapsules or the virus that they produce elicit a gross immune response, they were implanted into the mammary gland of female 2 months old BALB/c mice. The mice were sacrificed at various times after implantation to assess both the fate of the microcapsules and whether infectious virus was produced. Implanted microcapsules could be clearly seen embedded within the mammary fat pad for at least 6 weeks after implantation (Fig. 5A). Intriguingly, vascularisation occurred within the vicinity of the microcapsules in all animals analysed (Fig. 5A), presumably as a result of the production of angiogenic or growth factors by the packaging cells.

Sections made through the microcapsule and surrounding mammary tissue confirmed that blood vessels could be found in the immediate vicinity of the capsules (Fig. 5B). These sections also revealed a layer of connective tissue located between the microcapsule and the mammary tissue. There was no evidence of a gross inflammatory or immune response against the microcapsules or the virus producing cells that they contain.

In order to demonstrate that infectious retroviral vector particles had been released from the capsule and had infected the surrounding mammary tissue, some of the sections were analysed for expression of  $\beta$ -gal by X-gal staining. Cells expressing the  $\beta$ -gal gene were clearly visible outside of the microcapsule (Fig. 5C).

**Example 4**

This example describes the construction of a retroviral expression vector for intratumoral infection which contains the gene for rat cytochrome P450 2B1.

Expression vector pLX2B1, shown in Figure 6, was constructed by ligation of fragments obtained from plasmid pLX125 and pSW1 (Kedzie et al., 1991). The plasmid pLX125 was linearized with HpaI and the resulting blunt ends dephosphorylated using calf intestine phosphatase. The DNA was purified by separation on a 1% agarose gel, excision and preparation using the Qiaquick protocol (Qiagen). After ethanol precipitation the DNA was resuspended in water.

The cloning vector pSW1 was digested with SmaI and HincII to yield two blunt ended fragments. The digestion mixture was separated on a 1% agarose gel. The shortest fragment (1.5kb) containing the rat cytochrome P450 2B1 cDNA (Fuji-Kuriyama *et al.*, 1982) was excised and eluted using the Qiaquick DNA extraction protocol, ethanol precipitated and resuspended in water.

7,6 fMols of pLX125 and 24 fMols of the SmaI/HindII-fragment of pSW1 were mixed together and ligated for 3 days at 12°C using T4-ligase (Boehringer). The ligase was inactivated at 65°C for 10 min and the DNA butanol precipitated with a 10 fold volume of butanol. The precipitated DNA was resuspended in water and electroporated into DH10B-bacteria (Gibco). Ampicillin resistant colonies were selected, DNA prepared and test digested with SspBI/SalI, BamHI/SspBI, Pvul and BamHI. The final correct plasmid was designated pLX2B1.

#### Lipofection

One day before lipofection  $3 \times 10^5$  retroviral packaging cells PA317 (Miller and Buttimore, 1986) were seeded into 6 cm petri or culture dishes. On the day of infection 2 $\mu$ g of pLX2B1 were mixed with 100 $\mu$ l serum free media. In parallel 15 $\mu$ l of Lipofectamine (Gibco BRL) was mixed with 100 $\mu$ l serumfree media. The plasmid containing solution was added to the Lipofectamine-mix and incubated for 45min. After 35 min the cell were washed once with 2ml serum free media. 800 $\mu$ l of serum free media were added to the lipofection-mix and the resulting 1ml was put onto the prepared cells. After 6 hours 1ml Dulbecco's modified Eagles medium containing 10% FCS was added. The next day the cells were trypsinised and 1:10 diluted and seeded on a 100mm dish. After 24h the media was replaced with medium containing the neomycin analogue G418. Single cell clones or cell populations were isolated and analysed for expression of cytochrome P450.

#### Encapsulation

The retroviral vector producing packaging cells obtained are encapsulated as described in example 2 above.

### Implantation

The capsules obtained are introduced by "key hole" surgery near or in either transplanted or spontaneous tumours of BALB/c or GR mice. About six capsules of 1mm diameter are inserted at each operation site. The site of surgery is closed by 1 suture. The mice are then treated with cyclophosphamide or ifosfamide locally, by direct intratumoral injection of 100 $\mu$ l of 20mg/ml or systemic concentrations of 130mg CPA/kg body weight i.p. and 40-60mg IFO/kg body weight i.p. for up to a maximum of 10 weeks. During this period tumour size and macroscopic appearance is monitored daily. The mice are then sacrificed, the tissue containing the inserted capsules and tumour removed, and histological sections for light and electron microscopy prepared. These sections clearly show good engraftment of the capsules, vascularisation, and no evidence of the presence of lymphocytes indicative of a cellular immune response. These sections also show no sign of cell death or necrosis within the capsule. In contrast the tumour showed necrosis and macroscopically there was a clear reduction in size over the test period.

### Example 5

This example describes the construction of a stable cell line which expresses rat cytochrome P450 2B1 constitutively.

Expression vector pc3/2B1 was constructed by ligation of fragments obtained from plasmid pcDNA3 (Invitrogen) and pSW1 (Kedzie *et al.*, 1991).

The plasmid pcDNA3 was digested with Xhol/XbaI and the resulting sticky ended fragments dephosphorylated using calf intestine phosphatase. The DNA of the vector backbone was purified by separation on a 1% agarose gel, excision and preparation using the Qiaquick protocol (Qiagen). After ethanol precipitation the DNA was resuspended in water.

The cloning vector pSW1 was digested with Xhol and XbaI to yield two fragments. The digestion mixture was separated on a 1% agarose gel. The shortest fragment (1.5kb) containing the rat cytochrome P450 2B1 cDNA (Fuji-Kuriyama *et al.*, 1982) was excised and eluted using the Qiaquick DNA extraction protocol, ethanol precipitated and resuspended in water.

8,3 fMols of the pcDNA3 backbone and 24,8 fMols of the Xhol/XbaI-fragment of pSW1 were mixed together and ligated for 1 day at 12°C using T4-ligase (Boehringer). The ligase was inactivated at 65°C for 10 min and the DNA butanol precipitated with a 10fold volume of butanol. The precipitated DNA was resuspended in water and electroporated into DH10B-bacteria (Gibco). Ampicillin resistant colonies were selected, DNA prepared and test digested with EcoRI, BamHI, EcoRV and Xhol. The final correct plasmid was designated pc3/2B1.

#### Lipofection

Before the day of infection  $3 \times 10^5$  NIH3T3 cells were seeded into 35mm dishes. On the day of infection 2 $\mu$ g of pc3/2B1 was mixed with 100 $\mu$ l serum free media. In parallel 15 $\mu$ l Lipofectamine was mixed with 100 $\mu$ l serumfree media. The plasmid containing solution was added to the Lipofectamine-mix and incubated for 45min. After 35 min the cells were washed once with 2ml serum free media. 800 $\mu$ l of serum free media were added to the lipofection-mix and the resulting 1ml was put onto the prepared cells. After 6 hours 1ml DMEM (Glutamax) with 10% FCS were added. The next day the cells were trypsinised and diluted by factor ten and seeded on a 100mm dish. After 24h the media was replaced against neomycin media. After 14 days neomycin resistant clones were isolated and tested for presence and activity of the vector.

Capsules containing these cells were produced as described in Example 2 and implanted in mice near the tumour site. After treatment with cyclophosphamide or ifosfamide the efficacy of treatment was evaluated as described above.

### The Drawings

Fig. 1: Histological staining of encapsulated PA317 cells stably transfected with pBAG to demonstrate  $\beta$ -galactosidase expression.

Fig. 2: RT-PCR analysis of virus particles released by the capsules. (2B; lanes 1-4: medium taken after 2, 3, 5 and 6 weeks culture of capsules). Cell culture medium from nonencapsulated BAG virus producing cells was used as positive control (lane 5) and medium from nontransfected PA317 as negative control (lane 6). No signals were observed when the viral samples were digested with RNase before performing the RT-PCR analysis to ensure that the amplified band was derived from viral RNA (2C; lanes 1-4). Viral RNA prepared from nonencapsulated BAG virus producing cells, without RNase treatment, was used as a positive control in the RT-PCR reaction (lane 7).

Fig. 3: Cocultivation of encapsulated virus producing cells with NIH3T3 cells.  
(A) Target cells were seeded at low density one day before capsules containing retroviral vector producing packaging cells were added. Both cells and capsules were stained histologically for  $\beta$ -galactosidase activity several days later.  
(B) In order to verify that the  $\beta$ -galactosidase expressing target cells in A were derived from an infection event rather than by the escape of virus producing cells, genomic DNA was extracted from cells and PCR analysis was performed.

Fig. 4: Scanning electron microscopy showing the surface of the capsule in which pore like structures become detectable at high power magnification (x 75000). The white bar represents 100nm (the diameter of a retrovirus particle) indicating that these structures could represent the pores through which the virus is released from the capsule.

Fig. 5: Histological analysis of capsules implanted in the mammary gland of a mouse.(A)

(B) light microscopy of a section through a capsule after implantation into mouse mammary gland for four weeks (133 fold magnification).

(C) Infection of mouse mammary cells after implantation of BAG vector producing PA317 cell containing capsules.

Fig. 6 Structure of the expression vector pLX2B1 containing the gene for rat cytochrome P450 2B1 which will be controlled by the U3-MMTV promoter after promoter conversion.

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**Claims:**

1. Encapsulated cells producing viral particles comprising a core containing cells; and a porous capsule wall surrounding said core, said porous capsule wall being permeable to said viral particles.
2. Encapsulated cells according to claim 1 wherein said porous capsule wall consists of a polyelectrolyte complex formed from counter-charged polyelectrolytes.
3. Encapsulated cells according to claims 1 to 2 wherein said porous capsule wall consists of a polyelectrolyte complex formed from sulphate group-containing polysaccharides or polysaccharide derivatives or sulphonate group-containing synthetic polymers and polymers with quaternary ammonium groups.
4. Encapsulated cells according to claim 3 wherein the sulphate group-containing polysaccharides or polysaccharide derivative is cellulose sulphate, cellulose acetate sulphate, carboxymethylcellulose sulphate, dextran sulphate or starch sulphate, and the sulphonate group-containing synthetic polymer is a polystyrene sulphonate.
5. Encapsulated cells according to claim 3 wherein the polymer with quaternary ammonium groups is polydimethyldiallylammonium or polyvinylbenzyltrimethylammonium.
6. Encapsulated cells according to claims 1 to 5 wherein the porous capsule wall consists of a complex formed from cellulose sulphate and polydimethyldiallyl-ammonium.
7. Encapsulated cells according to claims 1 to 6 having the form of microcapsules with a diameter between 0.01 and 5 mm, preferably between 0.1 and 1 mm.
8. Encapsulated cells according to claims 1 to 7 wherein said capsule consist a spongy cellulose sulphate matrix forming the interior of the capsule wall surrounded by a capsule surface containing pores; said spongy matrix being filled with cells.

9. Encapsulated cells according to claims 1 to 8 wherein the surface pore size of the porous capsule wall is between 80 and 150 nm, preferably between 100-120 nm.
10. Encapsulated cells according to any of claims 1 to 9 wherein the viral particle produced by the encapsulated cells is a retroviral particle containing the genome of a retroviral vector.
11. Encapsulated cells according to claim 10 wherein the encapsulated cells producing retroviral particles is a packaging cell line transfected with an expression vector, said expression vector carrying a retroviral vector construct capable of infecting and directing the expression in target cells of one or more coding sequences carried by said retroviral vector construct; said packaging cell line harbouring at least one expression vector carrying genes coding for the proteins required for the genome of said retroviral vector construct to be packaged.
12. Encapsulated cells according to claim 11 wherein at least one of said coding sequences code for heterologous peptides selected from marker genes, therapeutic genes, antiviral genes, antitumour genes, and cytokine genes.
13. Encapsulated cells according to claim 12 wherein said marker gene is selected from the group consisting of marker genes which codes for proteins such as  $\beta$ -galactosidase, neomycin, alcohol dehydrogenase, puromycin, hypoxanthine phosphoribosyl transferase (HPRT), hygromycin and secreted alkaline phosphatase, and said therapeutic gene is selected from genes which codes for proteins such as Herpes Simplex Virus thymidine kinase, cytosine deaminase, guanine phosphoribosyl transferase (gpt), cytochrome P 450, cell cycle regulatory genes such as SDI, tumour suppresser genes which code for proteins such as p53, antiproliferation genes which code for proteins such as melittin, cecropin or cytokines such as IL-2.
14. Encapsulated cells according to claim 11 wherein the packaging cell line is selected from psi-2, psi-crypt, psi-AM, GP+E-86, PA317, and GP+envAM-12.

15. Encapsulated cells according to claim 11 wherein the expression vector is pBAG, pLXSN, p125LX, pLX2B1, or pc3/2B1 or derivatives thereof.
16. A process for the preparation of encapsulated cells according to claims 1 to 15 comprising suspending the cells producing viral particles in an aqueous solution of a polyelectrolyte, whereafter the suspension in the form of preformed particles is introduced into a precipitation bath containing an aqueous solution of a counter-charged polyelectrolyte.
17. A process according to claim 16 wherein the particle formation takes place by spraying.
18. A process according to claims 16 to 17 wherein the cells are suspended in an aqueous solution of a sulphate group-containing polysaccharide or polysaccharide derivative, or a sulphonate group-containing synthetic polymer.
19. A process according to claim 18 wherein the sulphate group-containing polysaccharide or polysaccharide derivative is selected from cellulose sulphate, cellulose acetate sulphate, carboxymethylcellulose sulphate, dextran sulphate or starch sulphate, and the sulphonate group-containing synthetic polymer is a polystyrene sulphonate.
20. A process according to claims 16 to 17 wherein the precipitation bath contain an aqueous solution of a polymer with quaternary ammonium groups.
21. A process according to claim 20 wherein the polymer with quaternary ammonium groups is polydimethyldiallylammonium or polyvinylbenzyl-trimethylammonium.
22. A process according to claims 16 to 17 wherein the cells are suspended in an aqueous solution of sodium cellulose sulphate, and introduced into a precipitation bath containing an aqueous solution of polydimethyldiallylammonium chloride.
23. A method according to claim 22 wherein the aqueous cellulosesulphate solution is composed of 0.5-50 %, preferably 2-5% sodium cellulose sulphate and

2-10%, preferably 5% fetal calf serum in buffered saline.

24. A method according to claim 22 wherein the aqueous solution in the precipitation bath is composed of 0.5-50 %, preferably 2-10 %, or more preferred 3 % polydimethylallylammonium chloride in buffered saline.

25. Encapsulated cells according to claims 1 to 15 produced by a process according to any of claims 16 to 24:

26. The use of the encapsulated cells according to claims 1 to 15 for the delivery of genes to target organ/cells comprising:

- a) Culturing the encapsulated cells in a suitable medium, and
- b) Implantation of the encapsulated cells into a living animal body, including a human.

27. The use according to claim 26 wherein the target organ/cells is the mammary gland, or the pancreas.

28. The use according to claim 26 wherein the target organ/cells are the smooth muscle cells surrounding the arteries.

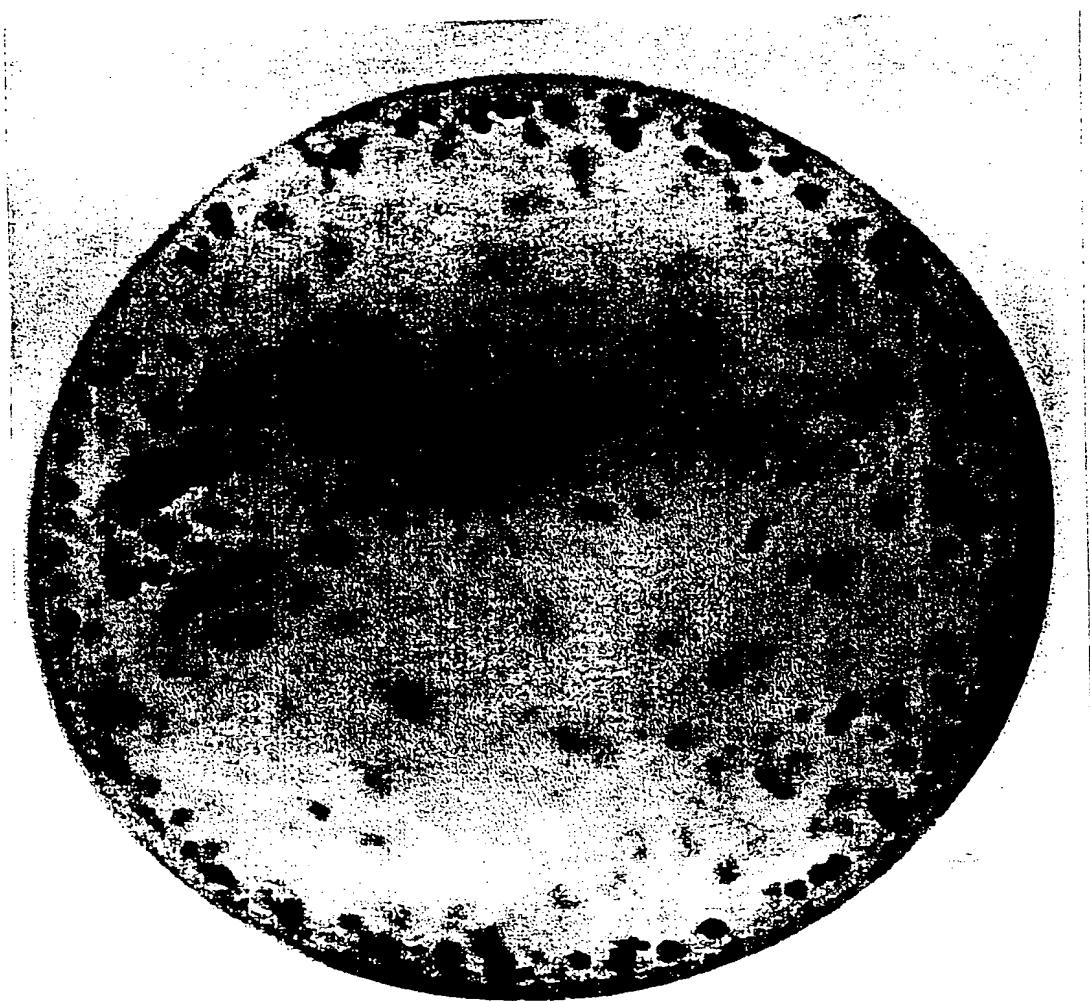


FIG. 1

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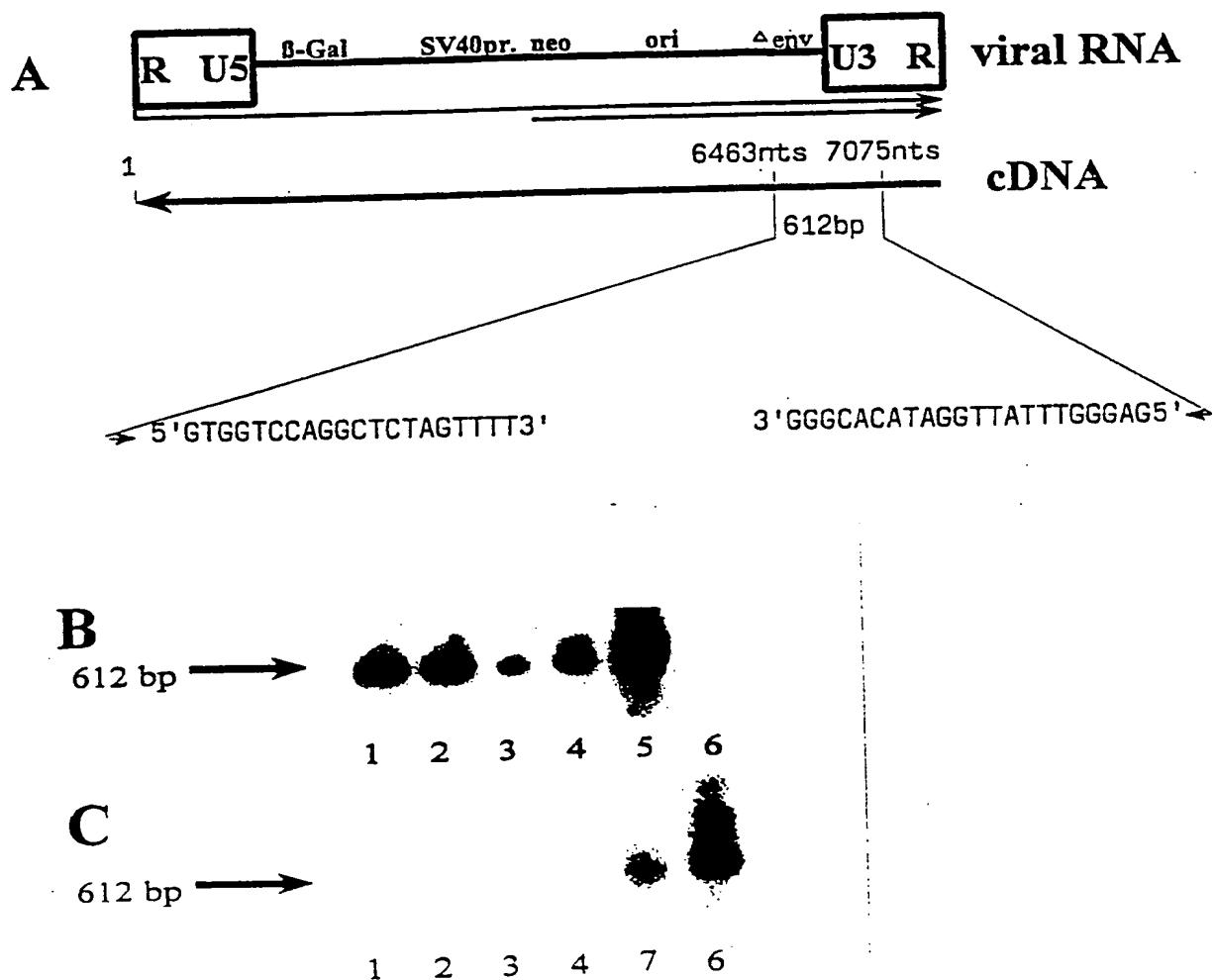


FIG. 2

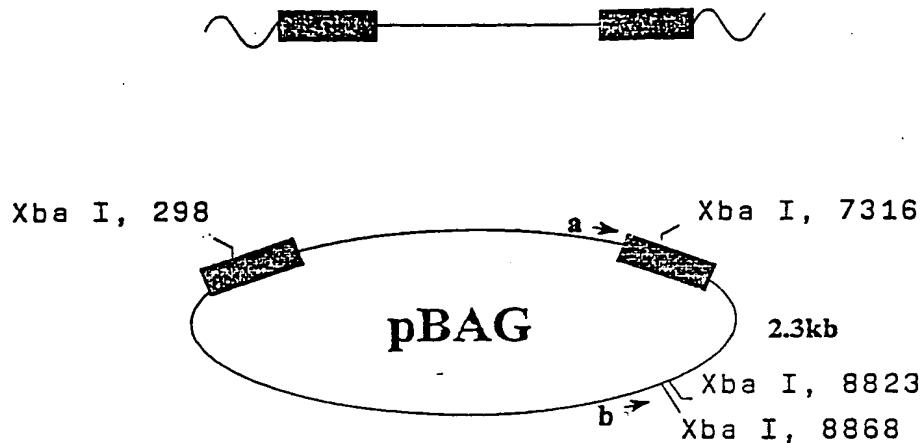
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FIG. 3A

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**integrated BAG after infection**

a) 5'TGTTGCTTCTATGCGGACCA 3'  
 b) 5'CCGCGCTTATTAGCCTGTTA 3'

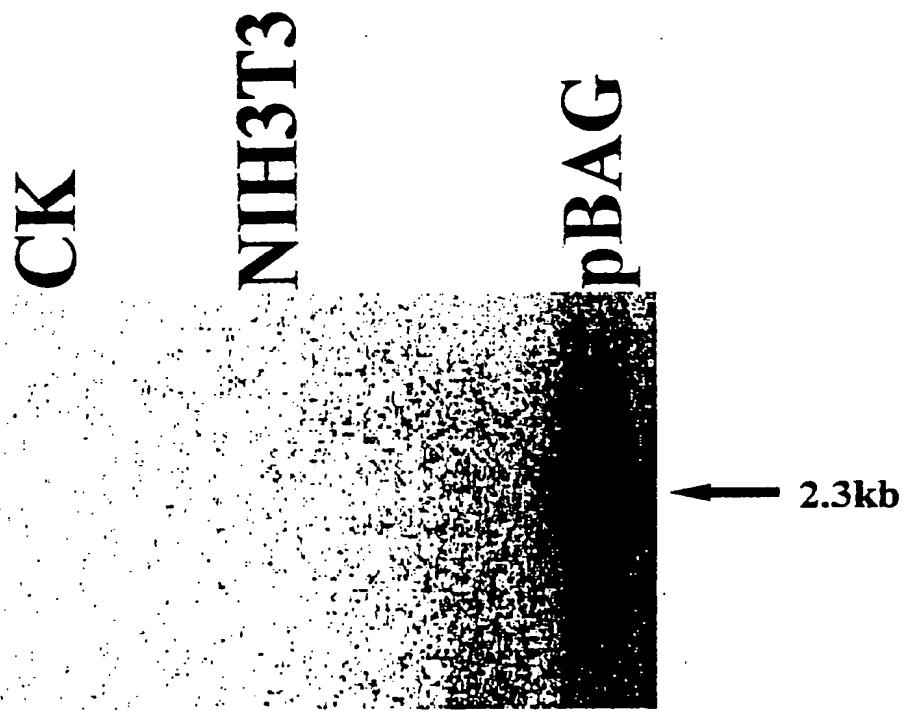


FIG. 3B

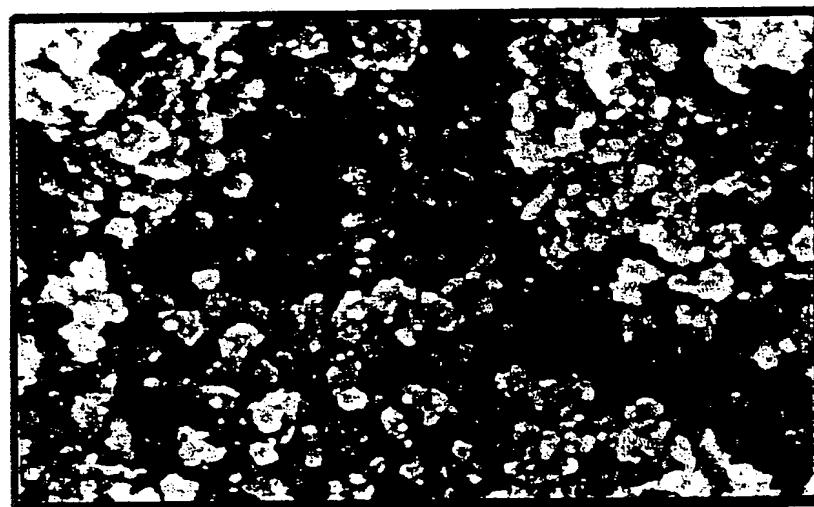
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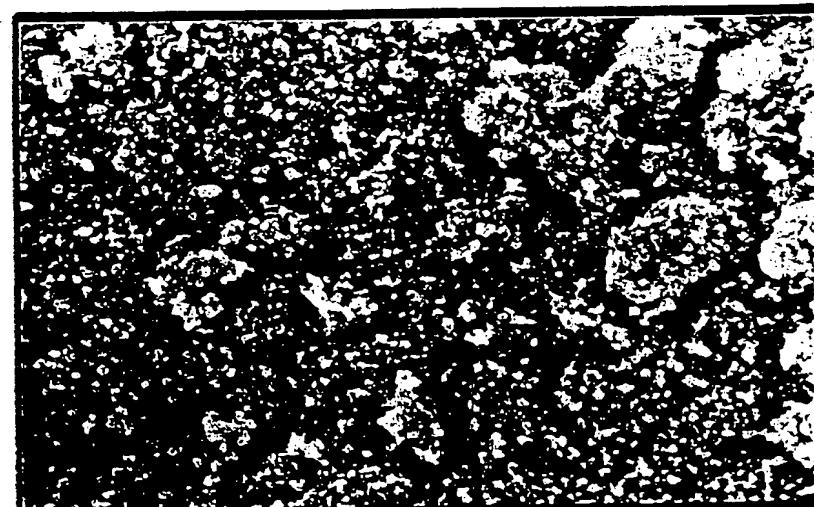
# Surface of microcapsule



x 75000



x 37000



x 10000

FIG. 4

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3 weeks



6 weeks

FIG. 5A



2 weeks



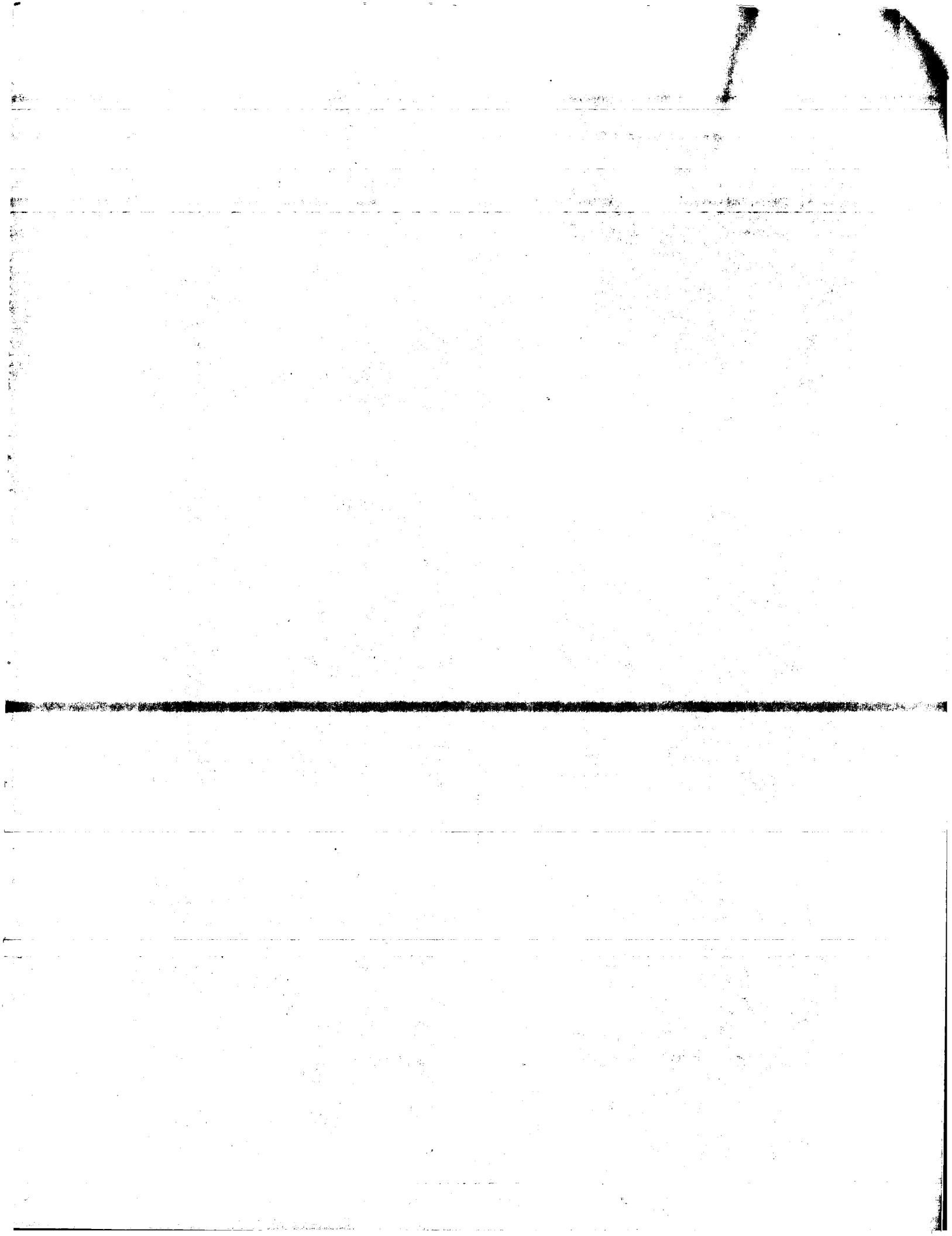
5 weeks



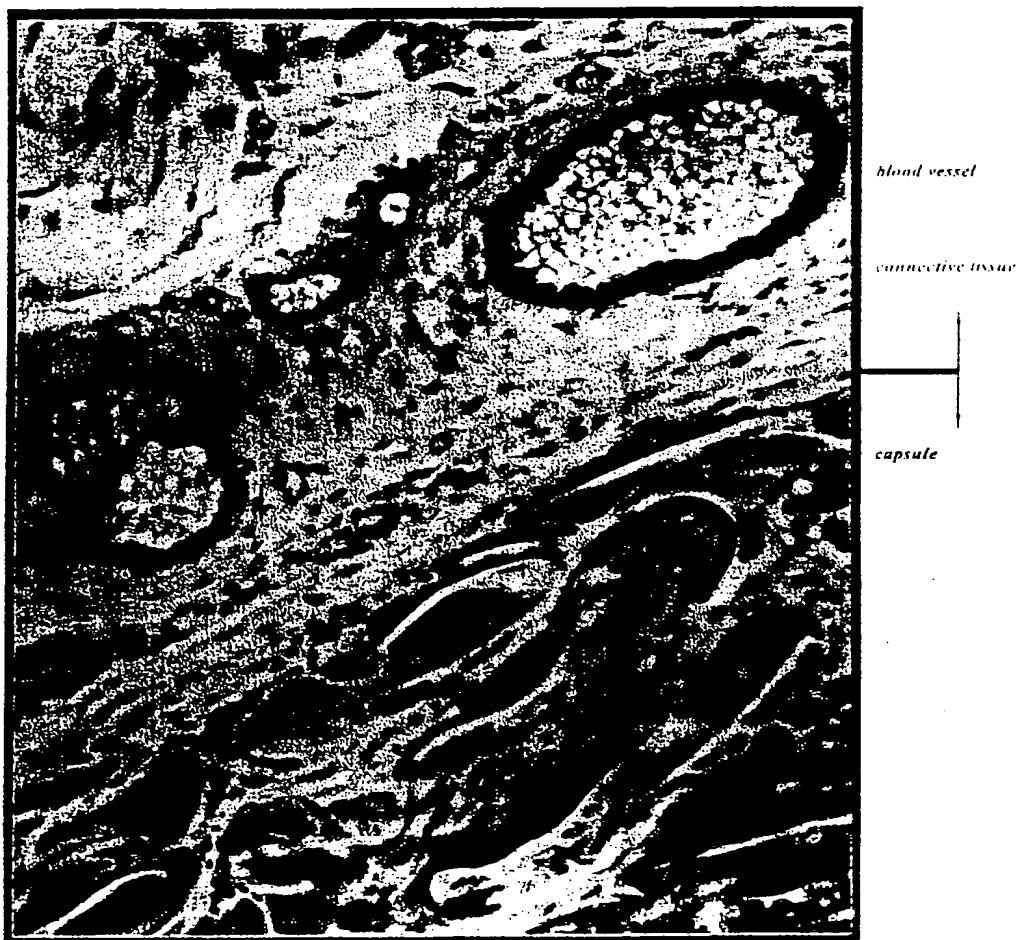
1 week



4 weeks

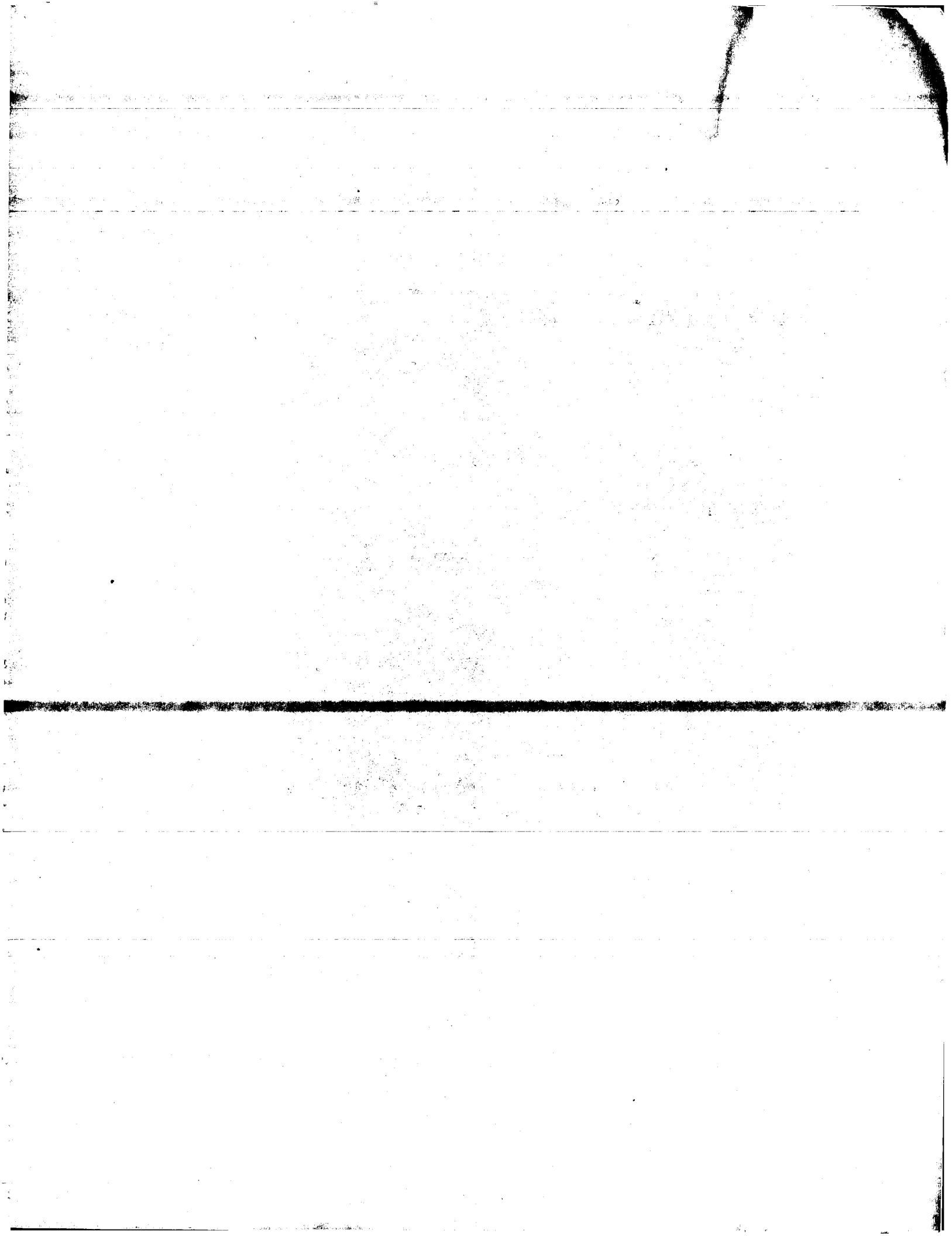


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*Magnification: 320x*

FIG. 5B



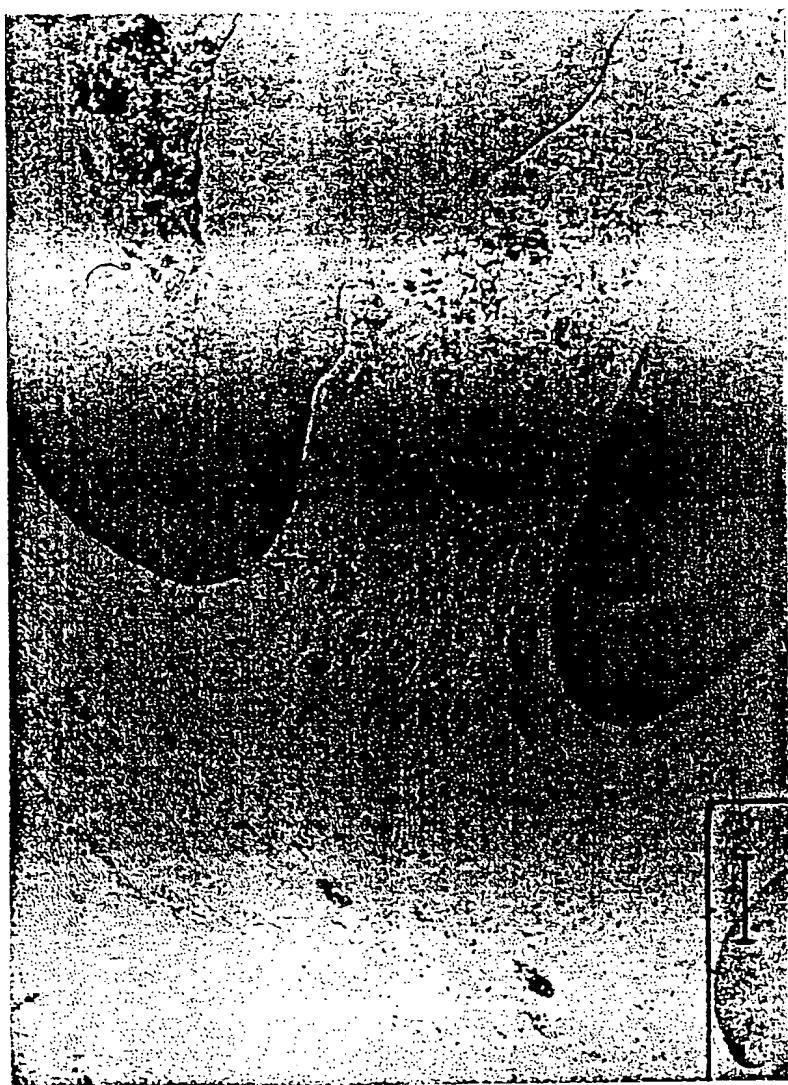
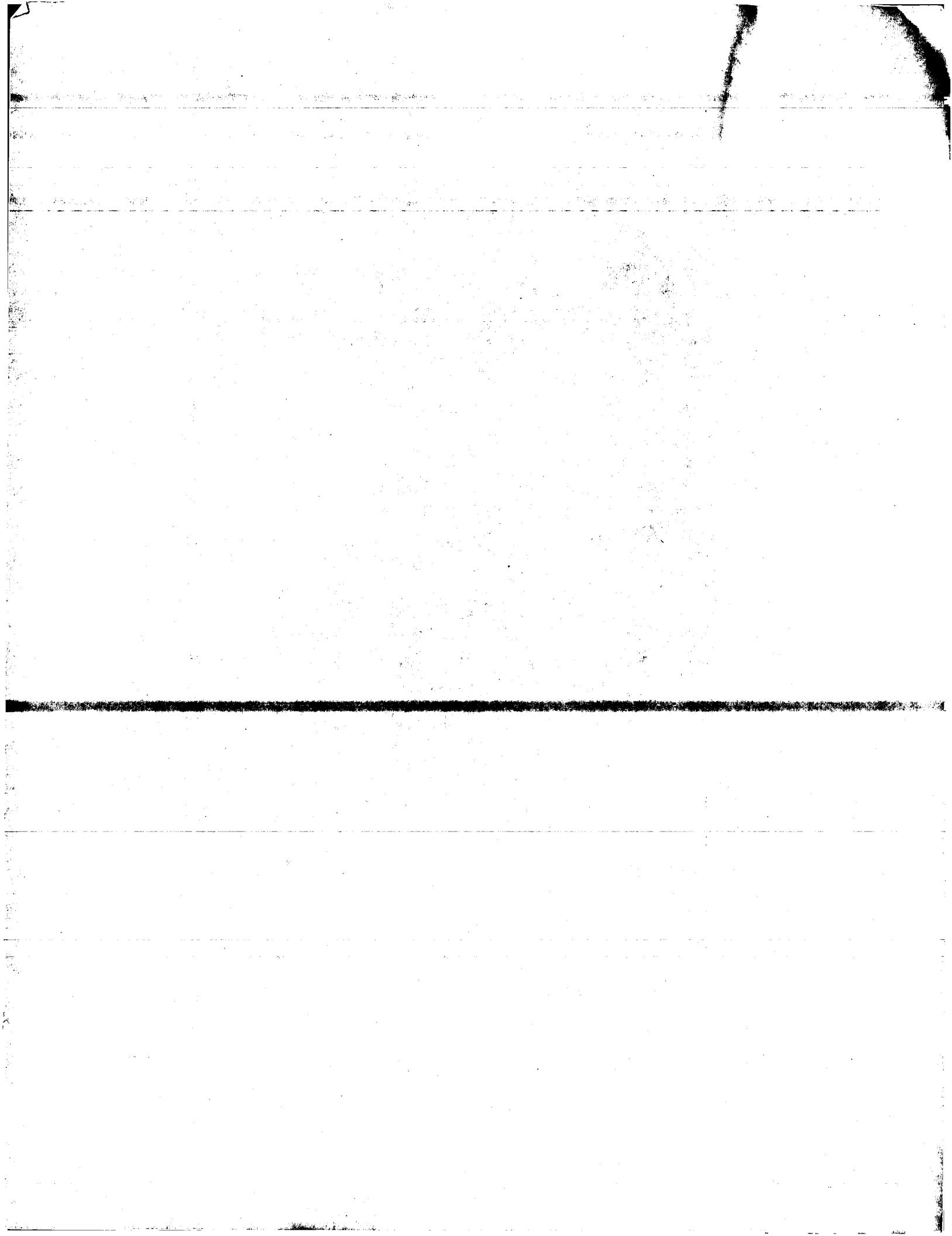


FIG. 5C



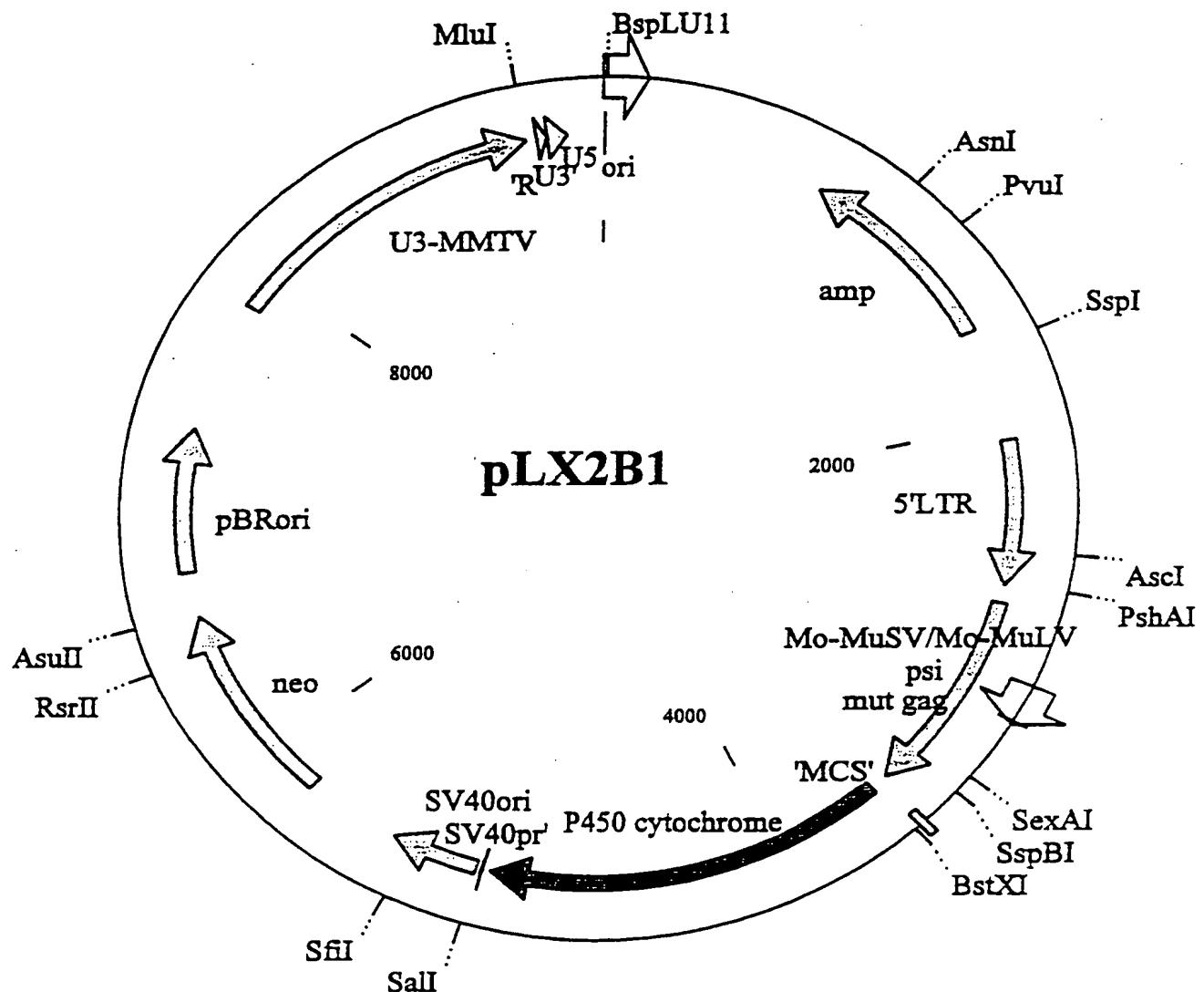


FIG. 6

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